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# Simplified Design Options for STS Payloads

Loads and Structural Dynamics Branch Report

Structures and Mechanics Division
Engineering Directorate

**April 1988**

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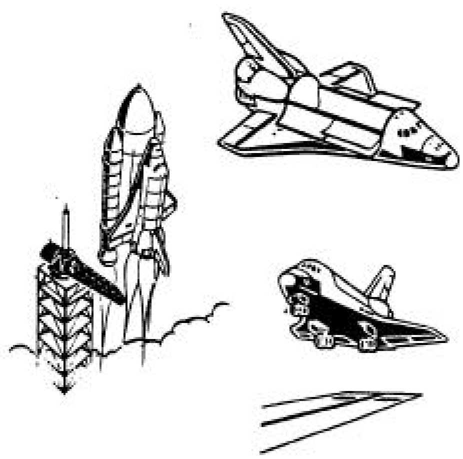

NASA
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**Lyndon B. Johnson Space Center**
Houston, Texas

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## Introduction

Payload hardware which is flown on the STS may be subjected to a wide variety of analysis and/or testing to certify it for flight. Such verification is dependent on the design requirements of the system involved, the organization for which the system is being developed, and the experience of the developer. A set of design options has been developed to provide a simple alternate approach to design and development of payload hardware. These options can be used in part or total to minimize the complexity of the system development. Options are specified which are applicable to primary structure and secondary structure. The STS will approve use of these options on a case-by-case basis.

General requirements for STS payloads are defined in JSC-07700, Volume XIV, Attachment 1, "Space Shuttle System Payload Accommodations."

LIMIT LOAD

The maximum expected load during any Shuttle flight event.

COUPLED LOADS

Loads determined by transient analysis of the combined Shuttle/payload system subjected to external forces of events such as liftoff and landing.

MERGING

Coupling of two or more structural dynamic math models. Each model may be in the form of mass and stiffness or mode shapes and frequencies.

DEPLOYABLE PAYLOAD

A payload which is planned for deployment from the Shuttle and is only returned under a mission abort condition.

RETURNABLE PAYLOAD

A payload which is planned for return from orbit by the Shuttle, whether it be on the mission which it is launched, or on subsequent missions.

LOAD FACTOR

The sum of all external forces acting on a payload in any one axis divided by the payload weight.

ANGULAR ACCELERATION

The total moment from all external forces acting on a payload about a given principal axis of the payload divided by the payload inertia about that axis.

RANDOM VIBRATION

A structural response associated with excitation which is of a random nature from sources such as rocket engine thrust, acoustics, etc.

PRIMARY STRUCTURE

The structure which is the primary load path into the Orbiter for all of the payload hardware.

FACTOR-OF-SAFETY

A factor which is multiplied times limit load to produce ultimate load.

MARGIN-OF-SAFETY

A ratio of the excess strength to the required strength.

$$MS = \frac{\text{Allowable Stress (or load)}}{\text{Applied Limit Stress (or load) X Factor-of-Safety}} - 1$$

ULTIMATE LOAD

Ultimate Factor-of-safety times limit load.

MATHEMATICAL MODEL

A finite element representation of a structure in the form of mass and stiffness, or vibration mode shapes and frequencies.

PRESSURE VESSEL

For Shuttle applications, any structure which (1) contains stored energy of more than .01 pounds of TNT equivalent; (2) will experience a design pressure greater than 100 PSI; or (3) contains a gas or liquid which will create a hazard, if released.

FRACTURE MECHANICS

Procedures and methods of determining behavior of cracks or crack-like defects in structures.

STRESS CORROSION

Cracking caused by the simultaneous presence of stress and a corrosive environment.

CONTAMINATION

Particles or molecules which may deposit on a payload surface or inhibit/effect field of view.

OUTGASSING

Molecular outflow from a material due to its surrounding environment.

STS

Space Transportation System

Design Load Factors - Primary Structure

STS payload developers often utilize preliminary load factors in Reference 1 for preliminary structural sizing and then utilize coupled loads analyses for design assessment and refinement. The coupled loads approach requires merging of Shuttle and payload finite element models and conducting transient response analyses utilizing STS provided forcing functions. This approach is relatively expensive and time consuming, but is considered a good approach to developing a minimum weight design.

In lieu of using coupled load analyses for payload design evolution, a set of conservative load factors can be used to size primary structure. These load factors should provide sufficient conservatism so that no design impacts would be expected in the STS Verification Loads Cycle. These load factors are specified for both deployable and planned return payloads. The load factors cover all flight events and should be analyzed in all combinations. These loads are intended for across-the-bay payload structures. Loads for sidewall mounted structures are covered in another section. The load factors are consistent with the coordinate system in Figure 1.

Table 1.1 Payload Design Limit Load Factors

| | Load Factor, G | | | Angular Acceleration, rd/s2 | | |
|---|---|---|---|---|---|---|
| | NX | NY | NZ | $\ddot{\theta}_x$ | $\ddot{\theta}_y$ | $\ddot{\theta}_z$ |
| Deployable Payloads | $\pm4.4$ | $\pm2.5$ | +5.0<br>-2.0 | $\pm$ 7.0 | $\pm14.0$ | $\pm$ 7.0 |
| Returnable Payloads | $\pm5.5$ | $\pm3.0$ | +8.0<br>-3.0 | $\pm10.0$ | $\pm20.0$ | $\pm10.0$ |

It should be noted that Orbiter/payload interface loads resulting from use of the above load factors could exceed Orbiter allowables defined in Reference 1. The preliminary design load factors given in Reference 1 can be used to calculate a less conservative set of interface loads for comparison to the allowables. The interface loads and Orbiter allowables should be discussed on an individual basis with JSC, since the allowables are a function of payload bay location.

Other load factor approaches are discussed in Reference 2.

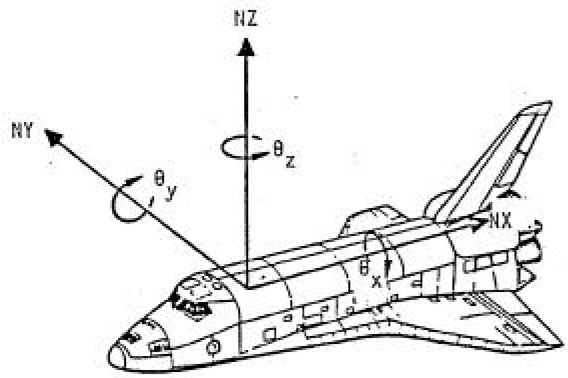


Figure 1: Orbiter Structural Coordinate System

STS Verification Loads Cycle

A verification loads cycle is conducted by the STS for each Shuttle mission to verify payload safety and compatibility. This loads cycle includes transient loads analyses of liftoff and landing conditions, and quasi-static analyses for the remaining load conditions. Math models of each payload are coupled with the Shuttle models for use in the transient analysis. External forces for liftoff include SRB and SSME thrust, SRB induced overpressure, winds, and launch pad restraint forces. The landing forces include aerodynamic and gear-impact dynamic forces.

Payload responses and interface loads from these analyses are provided to each payload developer for margin assessment. The interface loads are compared to Orbiter allowables as defined in Reference 1.

## Design Load Factors - Secondary Structure Components

Payload developers utilize a wide variety of methods to size secondary structure such as attachments for electronic boxes, experiment packages, equipment, etc. The STS provides random vibration environments at the longeron and keel attach points, payload bay acoustic levels, along with low frequency load factors to use for the secondary structural loading. As an alternative, a set of load factors for sizing of secondary structure and components is given in Table 1.2. These load factors are intended to encompass the effects of mechanically transmitted and acoustically induced random vibration as well as excitation from low frequency transients. The load factors should be applied in any axis, with a load factor equal to 25 percent of the primary load level applied to the remaining two orthogonal axes, simultaneously. For example, the design loads levels for a weight less than 20 pounds would be 40 g's in the critical load direction and 10 g's in each of the two remaining orthogonal axes.

Table 1.2 Design Limit Load Factors for Secondary Structure/Components

| Weight, lb | Load Factor, g |
|---|---|
| <20 | 40 |
| 20-50 | 31 |
| 50-100 | 22 |
| 100-200 | 17 |
| 200-500 | 13 |

These load levels should be sufficient to assure adequate strength for flight safety. However, electrical or mechanical systems are often subject to random vibration testing to ensure functionality. Many organizations have evolved their own requirements for vibration testing based on experience. Guidelines for environmental testing are given in Reference 3.

The random vibration environments at the Orbiter/payload interface and the payload bay acoustic environment are provided in Appendix A.

Design Load Factors - Sidewall Payloads

Design Limit Load factors for structural design of Orbiter sidewall mounted payloads are provided in Table 1.3. These design limit load factors are intended for use in lieu of performing coupled loads analysis for payloads that attach to the Orbiter sidewall/longeron on hardware such as the Adaptive Payload Carrier (APC), Increased Capability Adaptive Payload Carrier (ICAPC), and the Get Away Special (GAS) adapter beam. The low frequency portion of these load factors are based upon coupled liftoff and landing loads analyses for the GAS beam and canisters. The loads are based on the assumption that the payload has a minimum natural frequency of 35 hertz when constrained at the carrier interface. The effects of random vibration are included in the liftoff load factors. The effects of angular acceleration may be ignored for items which are cantilevered less than ten inches away from the carrier beam.

Table 1.3 - Limit Loads and Sidewall Mounted Payloads

| Event | | Load Factor, G | | | Angular Acceleration, rd/s$^2$ | | |
|---|---|---|---|---|---|---|---|
| | | NX | NY | NZ | $\ddot{\theta}_x$ | $\ddot{\theta}_y$ | $\ddot{\theta}_z$ |
| Liftoff | | | | | | | |
| | Case | | | | | | |
| | 1 | ±8.8 | ±7 | ±6 | ±75 | ±20 | ±55 |
| | 2 | ±7 | ±10.6 | ±6 | ±75 | ±20 | ±55 |
| | 3 | ±7 | ±7 | ±8.1 | ±75 | ±20 | ±55 |
| | 4 | ±8.8 | ±10.6 | ±8.1 | 0. | 0. | 0. |
| Landing | | ±6 | ±7 | ±8 | ±85 | ±30 | ±50 |

If random vibration testing is planned, the levels for sidewall payloads in Appendix A should be used as a minimum.

## Design Load Factors - Crew Cabin Hardware

Design limit load factors for crew cabin mounted hardware are provided in Table 1.4. The lift-off load includes the effect of low frequency and random induced loads. The low frequency loads are based on the assumption that the hardware has a minimum natural frequency of 35 hertz when constrained at its Orbiter interface. The load factors shall be considered in all combinations for each event.

Table 1.4 Load Factors for Cabin Mounted Payloads

| Event | Load Factor, G | | |
|---|---|---|---|
| | NX | NY | NZ |
| Lift-off | ±10.4 | ±6.1 | ±8.4 |
| Landing | ±6.25 | ±2.5 | ±12.5 |
| Emergency Landing* (Ultimate) | +20.0<br>-3.3 | ±3.3 | +10.0<br>-4.4 |

* Load in each axis acts independently, and the longitudinal load factors shall be directed within a 20° cone of the longitudinal axis

Environments for random vibration testing are specified the ICD 2-1M001, "Orbiter/Middeck Payload Standard ICD."

## Strength Verification/Factor-of-Safety

To ensure flight safety, the STS provides various options for strength verification (Reference 2). The strength may be verified by various static load test options or by combinations of criteria and/or testing which are equivalent. The intent of the strength verification requirements is to certify that the "as-built" structure has strength which is equal to or greater than required.

Composite structures and structures utilizing brittle materials such as Beryllium generally require strength testing of each flight article.

The requirement for strength verification by testing can possibly be waived through the use of an increased factor-of-safety (FOS). However, use of this option will be approved on a individual basis and requires demonstrated design experience. The use of a high factor-of-safety does not necessarily ensure that structural failure will not occur. A review of problems and failures experienced in manned spacecraft programs indicates that many failures would not have been precluded by an increased factor-of-safety.

Math Model Verification

Since transient dynamic loads on payloads are generally determined through coupled loads analyses, it is prudent to verify the mathematical model of the payload which is used in such coupled analyses. The verification of the model provides high confidence in the frequencies and mode shapes of the payload and thus confidence in the interaction of these properties with the Shuttle external forces and structural characteristics. Methods utilized for such verification include the classical modal survey, single and multi-point random vibration, sine vibration, and in some cases influence coefficient testing. Verification options are discussed in Reference 4.

Minimum Structural Frequency

The Shuttle flight control system can be affected by payload dynamic interaction depending on the payload weight and structural frequencies. The Orbiter is most sensitive to payload interaction during entry and landing, when the payload mass is significant relative to the Orbiter mass. The STS requirements are defined as a linear function of weight versus frequency, with heavy weights requiring higher minimum frequencies. The frequency restrictions correspond to the payload natural frequency when contrained at degrees-of-freedom which are normally constrained when in the Orbiter.

The most simple way to avoid the flight control interaction issue is to design to a minimum frequency above 6.0 hertz. If this constraint is not achieved the payload must provide a math model for a flight control assessment. Payloads weighing less than 5000 pounds need not consider the frequency restriction.